Synthesis of Cyclic Ethers from 3- and 4-Hydroxyalkylphosphonium Salts

Kentaro Okuma,* Osami Sakai, Tetsuji Hayano, Kosei Shioji, and Haruo Matsuyama[1]

Department of Chemistry, Faculty of Science, Fukuoka University, Jonan-ku, Fukuoka 814-0180

[1]Department of Applied Chemistry, Faculty of Engineering, Muroran Institute of Technology, 27-1 Mizumoto-cho, Muroran 050-8585

Received June 15, 2005; E-mail: kokuma@fukuoka-u.ac.jp

The reaction of 6-methylene-1,3-dioxepanes derived from 3-hydroxyalkyltriphenylphosphonium salts and paraformaldehyde with trimethylsilyl trifluoromethanesulfonate in the presence of *N*,*N*-diisopropylethylamine yielded novel 4-formyltetrahydropyrans. 3-Methylenetetrahydropyrans were synthesized by the reaction of 4-hydroxyalkyltriphenylphosphonium iodides with DBU and paraformaldehyde. 2,3-Dihydro-3-methylenebenzofuran was also obtained by the reaction of 2-hydroxybenzyltriphenylphosphonium bromide with butyllithium, followed by the addition of paraformaldehyde.

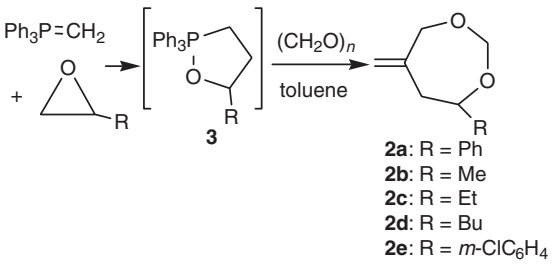
Cyclic ethers are important compounds for the synthesis of natural products. Since their synthetic utility in the formation of tetrahydropyrans **1** appears to be promising, many reports on the synthesis of substituted tetrahydropyrans have appeared. Typical methods include the acid-catalyzed cyclization of epoxy alcohols and terminal alkenols,[1,2] the Pd-catalyzed intramolecular 1,4-dialkoxyalkylation of terminal dienals,[3] the reaction of hydroxyallylsilane with aldehydes in the presence of TMSOTf,[4] the palladium-catalyzed trimethylenemethane reaction,[5] and the reaction of acetals with 2-(trimethylsilyloxyethyl)allyltrimethylsilane.[6] Previously, we communicated the synthesis of tetrahydropyrans **1** by the ring contraction of 1,3-dioxepanes **2** produced from sequential Wittig reactions.[7] We report herein on the full details of this reaction and a different type of the formation of six-membered cyclic ethers from phosphonium ylides.

Results and Discussion

One-Pot Synthesis of 6-Methylene-1,3-dioxepanes. Substituted 6-methylene-1,3-dioxepanes **2** were previously synthesized by the reaction of 1,2λ^5-oxaphospholanes **3** with paraformaldehydes.[8] Since 1,2λ^5-oxaphospholane **3** was easily hydrolyzed to give the corresponding diphenylphosphine oxide, we first tried a one-pot synthesis of **2**. The treatment of methylenetriphenylphosphorane with styrene oxide, followed by the addition of paraformaldehyde, resulted in the formation of 6-methylene-4-phenyl-1,3-dioxepane (**2a**) in 56% yield (Scheme 1). Other reactions were carried out in a similar manner (Table 1).

Since a new Wittig olefination by using 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) as a base was developed,[9] we applied this method to the synthesis of **2**. When 3-hydroxy-3-arylpropylphosphonium salts **4** were treated with DBU and paraformaldehyde, corresponding dioxepanes **2** were obtained in almost quantitative yields (Scheme 2, Table 2).

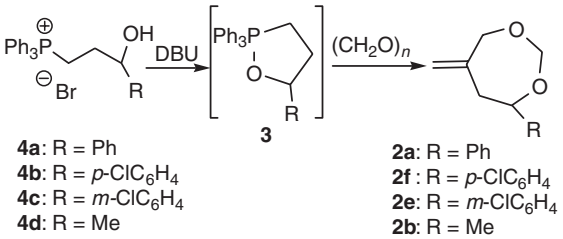
By using this improved method, dioxepanes **2** were synthesized on a large scale and could be used for their further investigation.



Scheme 1.

Table 1. One-Pot Synthesis of 6-Methylene-1,3-dioxepanes **2**

Epoxide R	Conditions		Products	
	Time/h	Temp	**2**	Yield/%
Ph	1	80 °C	**2a**	26
Ph	1	reflux	**2a**	56
Me	3	reflux	**2b**	33
Et	3	reflux	**2c**	52
Bu	2	reflux	**2d**	56
m-ClC_6H_4	1	reflux	**2e**	58



Scheme 2.

Ring Contraction of Dioxepanes 2. Since dioxepanes **2** are novel 7-membered cyclic acetals, their reactivity is our next interest. If these acetals react with a Lewis acid, a new type of aldehydes or alcohols will be formed. However, a normal Lewis acid, such as diethyl ether–borontrifluoride

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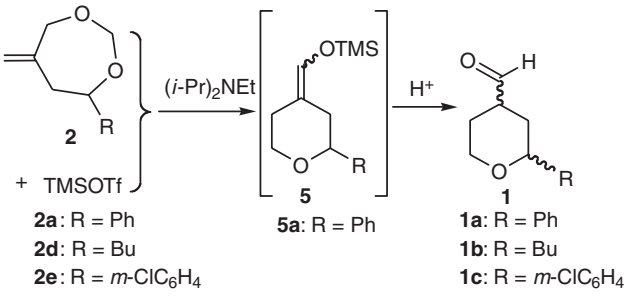
Table 2. Reaction of Salts **4** with DBU Followed by the Addition of Paraformaldehyde

4		Conditions		Products	
	R	Time/h	Temp	**2**	Yield/%
4a	Ph	5	rt	**2a**	0
4a	Ph	5	reflux	**2a**	96
4b	*p*-ClC_6H_4	5	reflux	**2f**	90
4c	*m*-ClC_6H_4	6	reflux	**2e**	92
4d	Me	5	reflux	**2b**	52

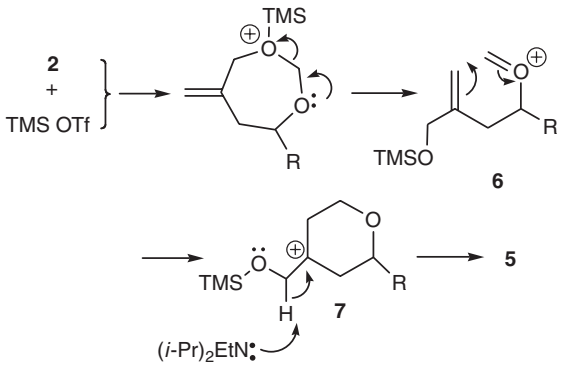


Scheme 3.

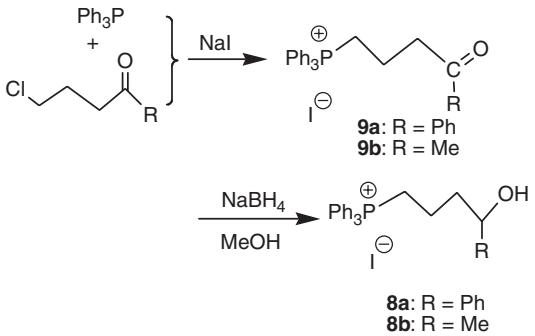
Table 3. Reaction of 6-Methylene-1,3-dioxepanes **2** with TMSOTf

2		Conditions			Products		
	R	Time/h	Temp	Base (equiv)	**1**	*cis*:*trans*	Yield/%
2a	Ph	5	rt	0.5	**1a**	—	0
2a	Ph	1	reflux	0.5	**1a**	—	0
2a	Ph	3	reflux	1	**1a**	—	10
2a	Ph	3	reflux	2	**1a**	1:1	77
2d	Bu	6	reflux	2	**1b**	1:1	40
2e	*m*-ClC_6H_4	3	reflux	2	**1c**	1:1	29[a)]

a) **2e** was recovered in 40% yield.



Scheme 4.



Scheme 5.

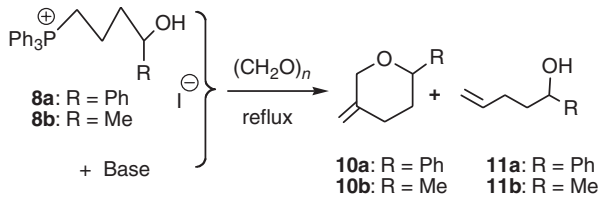
or $SnCl_2$, gave polymeric mixtures. We then chose trimethylsilyl trifluoromethanesulfonate (TMSOTf) as a Lewis acid. TMSOTf is a good reagent for a Michaelis–Arbuzov rearrangement,[10] the formation of thioacylsilanes,[11] and the ring expansion of 1,2,3-methanochromanes.[12] Dioxepane **2a** was treated with TMSOTf in the presence of *N*,*N*-diisopropylethylamine, followed by the addition of 1 M HCl to give the corresponding *cis*- and *trans*-4-formyl-2-phenyltetrahydropyrans (**1a**) (Scheme 3, Table 3). A mixture of *cis*- and *trans*-enol ethers **5** was also obtained as an intermediate.

Gassman et al. reported that the reaction of acetals with TMSOTf, followed by the addition of *N*,*N*-diisopropylethylamine, afforded the corresponding vinyl ethers in good yields.[13] In view of this result, we proposed the following mechanism. An initial attack of **2** with TMSOTf resulted in the formation of an oxonium ion intermediate **6**, which was further attacked by a double bond to give six-membered cyclic carbocation **7**, which finally produced the tetrahydropyran **1**, by the abstraction of a proton with diisopropylethylamine (Scheme 4).

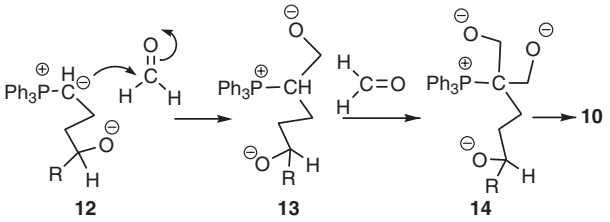
Gonzalez et al. have reported on the synthesis of 3-deoxy-3-nitroheptoseptanosides by the reaction of 1,4-dioxepanes with nitromethane in the presence of potassium fluoride as a catalyst.[14] Fukuzawa et al. reported on the effective transformation of aldoximes of 1,3-dioxepanes to nitriles by dehydration in the presence of scandium(III) triflate.[15] However, there is no report on ring contraction from methylene-1,3-dioxepanes.

Synthesis of Tetrahydropyrans from 4-Hydroxyalkylphosphonium Salts. It has been reported that reaction of γ-oxido ylides with paraformaldehyde afforded 3-methylenetetrahydrofurans.[16] We have extended this method to the synthesis of tetrahydropyrans by using δ-oxido ylides, prepared from 4-hydroxyalkyltriphenylphosphonium salts **8** and bases. 4-Hydroxy-4-phenylbutyltriphenylphosphonium iodide (**8a**) was synthesized by the following two-step reaction. 4-Chlorobutyrophenone reacted with triphenylphosphine in the presence of sodium iodide to give 4-oxo-4-phenylbutyltriphenylphosphonium iodide (**9a**), which was reduced by $NaBH_4$ to afford **8a** (Scheme 5).

The treatment of salt **8a** with butyllithium, followed by the addition of paraformaldehyde resulted in the formation of



Scheme 6.



Scheme 7.

Table 4. Reaction of 4-Hydroxylphosphonium Salts **7** with Base and Paraformaldehyde

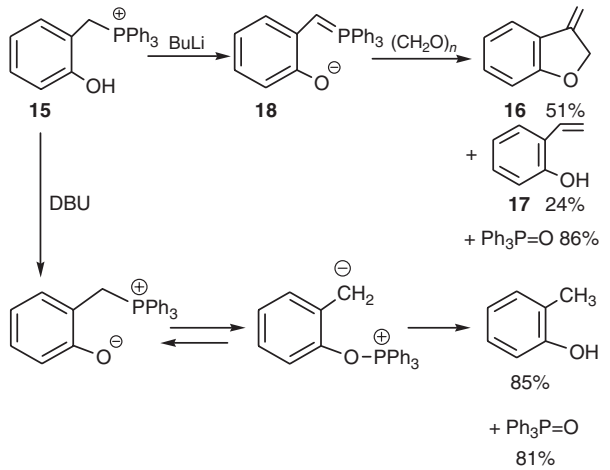
8		Conditions			Products			
	R	Base	Solvent	Time/h	**10**	Yield/%	**11**	Yield/%
8a	Ph	BuLi	Toluene	6	**10a**	26	**11a**	12
8a	Ph	NaH	Benzene	16	**10a**	19	**11a**	28
8a	Ph	DBU	Benzene	16	**10a**	30	**11a**	41
8a	Ph	DBU	CH_3CN	16	**10a**	65	**11a**	15
8b	Me	DBU	CH_3CN	16	**10b**	35	**11b**	20

5-methylene-2-phenyltetrahydropyran (**10a**) in 26% yield along with 1-phenyl-4-pentenol (**11a**) (12%). When the reaction was carried out by using DBU as a base, tetrahydropyran **10a** was obtained in 65% yield (Scheme 6, Table 4).

The reaction might proceed as follows. δ-Oxido ylide **12** reacted with paraformaldehyde to give the corresponding betaine **13**, which further reacted with another paraformaldehyde to afford another type of betaine **14**, which finally cyclized to afford **10** (Scheme 7).

Synthesis of 3-Methylenetetrahydrofuran. Since 3-methylenetetrahydrofuran was synthesized by γ-oxide ylide with paraformaldehyde,[16] we then applied the present method to the synthesis of benzofuran derivative. Commercially available 2-hydroxybenzyltriphenyphosphonium bromide (**15**) was treated with butyllithium, followed by the addition of paraformaldehyde to give 2,3-dihydro-3-methylenebenzofuran (**16**) in 51% yield along with *o*-vinylphenol (**17**), the normal Wittig reaction product, and triphenylphosphine oxide. When DBU was used as a base, the rearranged products (*o*-cresol and triphenylphosphine oxide) were obtained. Since the acidity of α-proton of salt **15** was lower than that of benzyltriphenylphosphonium bromide, DBU could not synthesize the γ-oxide phosphonium ylide **18**. Thus, a strong base plays an important role for the synthesis of benzofuran (Scheme 8).

In summary, we have succeeded in the synthesis of exomethylene cyclic ethers starting from hydroxyalkylphosphonium salts.



Scheme 8.

Experimental

General. All chemicals were obtained from commercial suppliers and were used without further purification. Analytical TLC was carried out on precoated plates (Merck silica gel 60, F254) and flash column chromatography was performed with silica (Merck, 70–230 mesh). All reactions were carried out in a nitrogen atmosphere. NMR spectra were measured on a JEOL GSX-400 (400 MHz for ^{1}H, 100 MHz for ^{13}C). The melting points were uncorrected.

One-Pot Synthesis of 6-Methylene-4-phenyl-1,3-dioxepane (2a). To a suspension of sodium hydride (60% mineral oil dispersion, 1.12 g, 28 mmol) in toluene (200 mL) was added methyltriphenylphosphonium bromide (7.75 g, 22 mmol) in one portion. After refluxing for 2 h, styrene oxide (2.40 g, 20 mmol) was added to this red solution. After refluxing for 14 h, paraformaldehyde (2.40 g, 60 mmol equivalent) was added to this suspension. After refluxing for 3 h, the reaction mixture was poured into water and the toluene layer was separated. The water layer was extracted with dichloromethane (25 mL) three times. The combined extract was dried over $MgSO_4$, filtered, and evaporated to give a pale-yellow oil, which was chromatographed over silica gel by elution with hexane to give 6-methylene-4-phenyl-1,3-dioxepane (**2a**) (2.13 g, 11.2 mmol), colorless oil (100–110 °C/1.9 mmHg). The spectral data were identical with that of an authentic sample.[8] Another reaction was carried out in a similar manner. **2b**: bp 40–55 °C/20 mmHg (lit.[8] bp 45–55 °C/17 mmHg). **2c**: bp 75–85 °C/20 mmHg (lit.[8] bp 80–90 °C/20 mmHg). **2d**: Colorless oil; bp 100–110 °C/25 mmHg. ^{1}H NMR ($CDCl_3$) δ 0.91 (t, 3H, J = 7 Hz, CH_3), 1.22–1.62 (m, 6H, CH_2), 2.40 (m, 2H, allyl CH_2), 3.50 (m, 1H, C<u>H</u>Bu), 4.24 (d, 1H, J = 14 Hz, OCH<u>H</u>), 4.38 (d, 1H, J = 14 Hz, OC<u>H</u>H), 4.64 (d, 1H, J = 7 Hz, OC<u>H</u>HO), 4.92 (brs, 2H, =CH_2), 4.99 (d, 1H, J = 7 Hz, OCH<u>H</u>O). ^{13}C NMR ($CDCl_3$) δ 14.07 (CH_3), 22.65 (CH_2), 28.01 (CH_2), 35.75 (CH_2), 43.31 (CH_2), 73.13 (CH_2O), 79.09 (OCH), 94.56 (OCH_2O), 113.84

(CH_2=), 145.59 (=C). Anal. Calcd for $C_{10}H_{18}O_2$: C, 70.55; H, 10.66%. Found: C, 70.29; H, 10.56%. **2e**: Colorless oil, ^{1}H NMR ($CDCl_3$) δ 2.60–2.76 (m, 2H, allyl CH_2), 4.33 (d, 1H, J = 14 Hz, OCHH), 4.47 (d, 1H, J = 14 Hz, OCHH), 4.56 (dd, 1H, J = 2 Hz, J = 10 Hz, OCHAr), 4.79 (d, 1H, J = 7 Hz, OCHHO), 5.03 (brs, 2H, =CH_2), 5.11 (d, 1H, J = 7 Hz, OCHHO), 7.20–7.42 (m, 4H, Ar). ^{13}C NMR ($CDCl_3$) δ 46.03 (CH_2), 73.48 (OCH_2), 80.62 (ArCH), 94.69 (OCH_2O), 115.48 (=CH_2), 124.28, 126.40, 129.94, 144.51 (Ar), 145.01 (=C). HRMS Calcd for $C_{12}H_{22}ClO_2$: M^+, 224.0604. Found: 224.0608 (M^+). Anal. Calcd for $C_{12}H_{13}ClO_2$: C, 63.93; H, 5.90%. Found: C, 64.15; H, 5.83%.

Reaction of 3-Hydroxy-3-*p*-chlorophenyltriphenylphosphonium Bromide (4b) with DBU Followed by the Addition of Paraformaldehyde. To a solution of **4b** (2.55 g, 5.0 mmol) in dichloromethane (35 mL) was added DBU (2.28 g, 15.0 mmol) in one portion. After refluxing for 30 min, paraformaldehyde (0.45 g, 15 mmol) was added in one portion and refluxed for 5 h. The reaction mixture was washed with water (15 mL × 3), dried over sodium sulfate, filtered, and evaporated to give pale-yellow orange oily crystals, which were chromatographed over silica gel by elution with hexane–dichloromethane (1:1) to afford 3-*p*-chlorophenyl-5-methylene-1,3-dioxepane (1.08 g, 4.5 mmol). **2f**: Colorless oil: ^{1}H NMR ($CDCl_3$) δ 2.62 (dd, 1H, J = 13 Hz, J = 1 Hz, allyl CHH), 2.70 (dd, 1H, J = 13 Hz, J = 10 Hz, allyl CHH), 4.33 (d, 1H, J = 14 Hz, OCHH), 4.50 (d, 1H, J = 14 Hz, OCHH), 4.56 (dd, 1H, J = 2 Hz, J = 10 Hz, OCHAr), 4.79 (d, 1H, J = 7 Hz, OCHHO), 5.03 (brs, 2H, =CH_2), 5.11 (d, 1H, J = 7 Hz, OCHHO), 7.32 (s, 4H, Ar). ^{13}C NMR ($CDCl_3$) δ 46.07 (CH_2), 73.52 (OCH_2), 80.71 (ArCH), 94.69 (OCH_2O), 115.42 (=CH_2), 127.53, 128.79, 133.50, 141.01 (Ar), 145.10 (=C). Anal. Calcd for $C_{12}H_{13}ClO_2$: C, 64.15; H, 5.83%. Found: C, 63.86; H, 5.87%.

Reaction of Dioxepane 2a with TMSOTf in the Presence of *N*,*N*-Diisopropylethylamine. To a solution of **2a** (0.19 g, 1.0 mmol) and *N*,*N*-diisopropylethylamine (0.26 g, 2.0 mmol) in dichloromethane (10 mL) was added a solution of TMSOTf (0.22 g, 1.0 mmol) in dichloromethane (4 mL). After refluxing for 2 h, the reaction mixture was poured into aqueous 1 M HCl and the dichloromethane layer was separated. The aqueous layer was extracted with dichloromethane (5 mL) three times. The combined extract was washed with water, dried over $MgSO_4$, filtered, and evaporated to give a pale-yellow oil, which was distilled by bulb to bulb to give a mixture of *cis*- and *trans*-4-formyl-2-phenyltetrahydropyrans (**1a**) (0.21 g, 1.1 mmol, 77%). bp 110–140 °C/2 mmHg. HRMS Calcd for $C_{11}H_{14}O_2$: 199.0994. Found: 199.0981 (M^+). *cis*-**1a**: ^{1}H NMR ($CDCl_3$) δ 1.58 (q, 1H, J = 12 Hz, CHH), 1.68 (dq, 1H, J = 12 Hz and 4 Hz, CHH), 1.88 (d, 1H, J = 10 Hz, CHH), 2.10 (d, 1H, J = 13 Hz, CHH), 2.66 (tt, 1H, J = 12 Hz and 4 Hz, CHH), 3.64 (t, 1H, J = 11 Hz, OCHH), 4.27 (dd, 1H, J = 11 Hz and 4 Hz, OCHH), 4.38 (d, 1H, J = 12 Hz, OCH), 7.23–7.37 (m, 5H, Ph), 9.62 (CHO). ^{13}C NMR ($CDCl_3$) δ 25.50 (CH_2), 33.23 (CH_2), 48.17 (CH_2), 67.34 (CH), 78.77 (OCH), 125.59, 127.53, 128.21, 141.80 (Ph), 201.85 (CHO). *trans*-**1a**: ^{1}H NMR ($CDCl_3$) δ 1.91 (m, 1H, CHH), 2.05 (m, 1H, CHH), 2.12 (brd, 1H, J = 11 Hz, CHH), 2.32 (brd, 1H, J = 14 Hz, CHH), 2.77 (brs, 1H, CH), 3.64 (dt, 1H, J = 12 Hz and 3 Hz, OCHH), 4.01 (dd, 1H, J = 12 Hz and 4 Hz, OCHH), 4.30 (dd, 1H, J = 12 Hz and 3 Hz, OCH), 7.23–7.37 (m, 5H, Ph), 9.88 (CHO). ^{13}C NMR ($CDCl_3$) δ 24.23 (CH_2), 31.79 (CH_2), 44.63 (CH_2), 64.98 (CH), 75.89 (OCH), 125.33, 127.23, 128.06, 141.92 (Ph), 203.32 (CHO).

1b: Colorless oil: 70–75 °C/0.3 mmHg. Anal. Calcd for $C_{10}H_{18}O_2$: C, 70.55; H, 10.66%. Found: C, 70.29; H, 10.56%. Both isomers could not be separated. *cis*-**1b**: ^{1}H NMR ($CDCl_3$) δ 0.89 (t, 3H, J = 8 Hz, CH_3), 1.20–2.00 (m, 10H, CH_2), 2.50 (m, 1H, CH), 3.29 (m, 1H, CH), 3.48 (t, 1H, J = 12 Hz, OCHH), 4.12 (brd, 1H, J = 12 Hz, OCHH), 9.61 (d, 1H, J = 1 Hz, CHO). ^{13}C NMR ($CDCl_3$) δ 14.16 (CH_3), 22.82 (CH_2), 25.83 (CH_2), 27.64 (CH_2), 31.21 (CH_2), 36.11 (CH_2), 48.01 (CH), 66.93 (CH_2), 76.82 (CH), 202.48 (CHO). *trans*-**1b**: Colorless oil; ^{1}H NMR ($CDCl_3$) δ 0.89 (t, 3H, J = 8 Hz, CH_3), 1.20–1.65 (m, 7H, CH_2), 1.89 (m, 1H, CHH), 2.03 (d, 1H, J = 14 Hz, CHH), 2.10 (d, 1H, J = 16 Hz, CHH), 2.67 (brs, 1H, CH), 3.26 (brs, 1H, CH), 3.41 (dt, 1H, J = 12 Hz and 3 Hz, OCHH), 3.86 (brd, 1H, J = 12 Hz, OCHH), 9.80 (s, 1H, CHO). ^{13}C NMR ($CDCl_3$) δ 13.98 (CH_3), 22.63 (CH_2), 24.58 (CH_2), 27.48 (CH_2), 30.11 (CH_2), 35.74 (CH_2), 44.39 (CH), 64.63 (CH_2), 74.18 (CH), 202.68 (CHO).

1c: Colorless oil: Anal. Calcd for $C_{12}H_{13}ClO_2$: C, 64.15; H, 5.83%. Found: C, 63.87; H, 5.87%. Both isomers could not be separated. *cis*-**1c**: ^{1}H NMR ($CDCl_3$) δ 1.54 (m, 1H, CHH), 1.73 (m, 1H, CHH), 1.92 (brd, 1H, J = 14 Hz, CHH), 2.13 (brd, 1H, J = 14 Hz, CHH), 2.68 (br, 1H, CH), 3.62 (dt, 1H, J = 12 Hz and 3 Hz, OCHH), 4.28 (brd, 1H, J = 12 Hz, OCHH), 4.36 (brd, 1H, J = 12 Hz, OCH), 7.18–7.38 (m, 4H, Ar), 9.64 (CHO). ^{13}C NMR ($CDCl_3$) δ 25.62 (CH_2), 33.41 (CH_2), 48.24 (CH_2), 67.63 (CH), 78.31 (OCH), 124.11, 126.16, 129.91, 134.59, 144.30 (Ar), 202.25 (CHO). *trans*-**1c**: ^{1}H NMR ($CDCl_3$) δ 1.85 (m, 1H, CHH), 2.05 (m, 1H, CHH), 2.12 (brd, 1H, J = 14 Hz, CHH), 2.33 (brd, 1H, J = 14 Hz, CHH), 2.77 (brs, 1H, CH), 3.57 (dt, 1H, J = 12 Hz and 3 Hz, OCHH), 4.01 (brd, 1H, J = 12 Hz, OCHH), 4.36 (brd, 1H, J = 12 Hz, OCH), 7.20–7.38 (m, 4H, Ar), 9.89 (CHO). ^{13}C NMR ($CDCl_3$) δ 24.40 (CH_2), 31.79 (CH_2), 44.63 (CH_2), 64.98 (CH), 75.89 (OCH), 125.33, 127.23, 128.06, 141.92 (Ph), 203.32 (CHO).

A mixture of *cis*- and *trans*-trimethylsiloxymethylene-2-phenyltetrahydropyrans (**5a**) (0.40 g, 1.54 mmol) was obtained when the mixture was extracted with water. *cis*- and *trans*-**5a**: Colorless oil; ^{1}H NMR ($CDCl_3$) δ 0.19 (s, 18H, TMS), 1.98 (d, 1H, J = 12.0 Hz, CHH), 2.00 (d, 1H, J = 12 Hz, CHH), 2.07 (m, 1H, CHH), 2.20 (m, 2H, CH_2), 2.33 (m, 1H, CHH), 2.73 (d, 1H, J = 12.0 Hz, CHH), 2.97 (d, 1H, J = 12.0 Hz, CHH), 3.51 (m, 2H, OCHH), 4.17 (m, 2H, OCHH), 4.25 (m, 2H, OCH), 6.18 (s, 2H, =CH), 7.22–7.43 (m, 10H, Ph). ^{13}C NMR ($CDCl_3$) δ −0.32 (TMS), 25.99 (CH_2), 30.21 (CH_2), 33.74 (CH_2), 38.26 (CH_2), 68.51 (OCH_2), 68.53 (OCH_2), 79.91 (OCH), 81.16 (OCH), 116.87 (=C), 116.98 (=C), 125.71, 125.85, 127.29, 128.16, 132.01 (=CHOTMS), 132.11 (=CHOTMS), 142.43, 142.51 (Ph). HRMS Calcd for $C_{15}H_{22}O_2Si$: M^+, 262.1389. Found: 262.1371 (M^+).

Synthesis of 4-Hydroxy-4-phenylbutyltriphenylphosphonium Iodide (8a). To a solution of triphenylphosphine (2.62 g, 10 mmol) in toluene (100 mL) was added a solution of 4-chlorobutyrophenone (2.00 g, 11 mmol) and sodium iodide (1.80 g, 12 mmol) in toluene (25 mL). After stirring for 8 h, colorless crystals were precipitated, which were filtered to give colorless crystals of 3-benzoylpropyltriphenylphosphonium iodide (**9a**) (4.28 g, 8.0 mmol). To a solution of salts **9a** in methanol (50 mL) was added sodium tetrahydroborate (0.30 g, 8.0 mmol) in one portion. After refluxing for 6 h, the reaction mixture was poured into water (50 mL) and extracted from dichloromethane (20 mL) three times. The combined extract was dried over $MgSO_4$, filtered, and evaporated to give a colorless solid, which was recrystallized from methanol to give colorless crystals of 4-hydroxy-4-phenylbutyltriphenyphosphonium iodide (**8a**) (3.75 g, 7.0 mmol). ^{1}H NMR ($CDCl_3$) δ 1.60–1.70 (m, 1H, CH_2), 1.77–1.90 (m, 1H, CH_2),

2.05 (m, 2H, CH_2), 3.50–3.65 (m, 1H, PC<u>H</u>H), 3.85–3.95 (m, 1H, PCH<u>H</u>), 4.98 (m, 1H, PhCH), 7.05–7.32 (m, 5H, Ph), 7.60–7.80 (m, PPh_3). ^{13}C NMR ($CDCl_3$) δ 19.10 (CH_2), 22.36 (d, CH_2), 38.80 (d, CH_2), 71.74 (CH), 109.99, 118.30, 126.10, 126.75, 128.15, 130.60, 133.67, 135.04, 145.15 (Ph). Elemental analysis was carried out by changing to its tetraphenylborate. mp 160–161 °C, Anal. Calcd for $C_{52}H_{48}$BOP: C, 85.47; H, 6.62%. Found: C, 85.72; H, 6.85%.

8b: mp 186–188 °C. ^{1}H NMR ($CDCl_3$) δ 1.16 (d, 3H, $J = 6.4$ Hz, Me), 1.68–1.91 (m, 4H, CH_2CH_2), 3.52 (m, 1H, PC<u>H</u>H), 3.82 (m, 1H, PCH<u>H</u>), 4.05 (m, 1H, CH), 7.65–7.85 (m, 15H, Ph). ^{13}C NMR ($CDCl_3$) δ 19.61 (Me), 23.20 (CH_2), 24.38 (d, $J_{P-C} = 50$ Hz, CH_2), 38.58 (d, $J_{P-C} = 16$ Hz), 66.20, 118.43 (d, $J_{P-C} = 86$ Hz), 130.71 (d, $J_{P-C} = 12$ Hz), 133.93, 135.24 (Ph). Anal. Calcd for $C_{23}H_{26}$OPI: C, 57.99; H, 5.50%. Found: C, 58.09; H, 5.53%.

Reaction of Salt 8a with Butyllithium Followed by the Addition of Paraformaldehyde. To a suspension of salt **8a** (0.538 g, 1.0 mmol) in benzene (30 mL) was added a solution of butyllithium (2.5 M in hexane, 1.0 mL) in hexane at room temperature. After stirring for 2 h, paraformaldehyde (0.30 g, 10 mmol) was added to this solution in one portion. After refluxing for 8 h, the reaction mixture was poured into water (30 mL) and extracted with dichloromethane (20 mL × 3). The combined extract was dried over $MgSO_4$, filtered, and evaporated to give pale-yellow crystals, which were chromatographed over silica gel by elution with hexane: dichloromethane (1:1) to afford 5-methylene-2-phenyltetrahydropyran (**10a**). Colorless oil; 0.045 g, 0.26 mmol. 135–150 °C/2 mmHg (lit.[17] 100–150 °C/16 mmHg). 1-Phenyl-4-pentenol (**11a**) was eluted second (0.020 g, 0.12 mmol). The spectral data were identical with the reported one.[18] By elution with dichloromethane, triphenylphosphine oxide (0.21 g, 0.76 mmol) was obtained.

Reaction of Salts 8a with DBU Followed by the Addition of Paraformaldehyde. To a solution of salt **8a** (0.538 g, 1.0 mmol) in acetonitrile (20 mL) was added DBU (0.38 g, 2.5 mmol) in acetonitrile (5 mL) at room temperature. After refluxing for 2 h, paraformaldehyde (0.30 g, 10 mmol) was added in one portion. After being stirred for 10 h, the reaction mixture was poured into water and extracted with dichloromethane (15 mL) three times. The combined extract was washed with water, dried over $MgSO_4$, and evaporated to give a pale-yellow oil, which was chromatographed over silica gel by elution with hexane–dichloromethane to give a colorless oil of tetrahydropyrans **10a** (0.113 g, 0.65 mmol). 1-Phenyl-4-pentenol (**11a**) was eluted next (0.025 g, 0.15 mmol).[19] Similarly, 2-methyl-5-methylenetetrahydropyran (**10b**) was obtained in 35% yield. **10b**: Colorless oil: bp 70–95 °C/25 mmHg). ^{1}H spectral data of **10b** was identical with the reported data.[17]

Reaction of 2-Hydroxybenzyltriphenylphosphonium Bromide (15) with BuLi Followed by the Addition of Paraformaldehyde. To a solution of 2-hydroxybenzyltriphenylphosphonium bromide (**15**) (0.90 g, 2.0 mmol) in THF (30 mL) was added BuLi (2 M in hexane, 3.0 mL) at room temperature. After stirring for 1 h, paraformaldehyde (0.30 g, 10 mmol) was added in one portion and the suspension was refluxed for 5 h. The reaction mixture was poured into water and extracted with dichloromethane (15 mL × 3). The combined extract was dried over sodium sulfate, filtered, and evaporated to give pale-orange oily crystals, which were chromatographed over silica gel by elution with hexane–dichloromethane and dichloromethane to afford 2,3-dihydro-3-methylenebenzofuran (**16**) (0.14 g, 1.05 mmol), *o*-vinylphenol (**17**) (0.058 g, 0.48 mmol), and triphenylphosphine oxide (0.48 g, 1.72 mmol). **16**: Colorless oil: bp 85–105 °C/20 mmHg (lit.[20] 75–80 °C/12 mmHg).

When **15** (0.90 g, 2.0 mmol) was treated with DBU (0.61 g, 4.0 mmol), followed by the addition of paraformaldehyde (0.30 g, 10 mmol) in refluxing dichloromethane, *o*-cresol (0.18 g, 1.70 mmol) was obtained in 85% yield along with triphenylphosphine oxide (0.45 g, 1.62 mmol).

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